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Investigations on m=2, n=1 Tearing Mode Stabilisation with ECRH at ASDEX Upgrade

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Introduction

Neoclassical tearing modes (NTMs) occurring in high β discharges have a substantial influence on the performance of a tokamak and can even lead to disruptions. The suppression and avoidance of these instabilities is considered as a primary task for future machines like ITER. Investigations have shown that the ITER plasma will have a strong tendency to develop a 2/1 NTM. NTMs are characterised by magnetic islands in the plasma which are driven by a flattening of the profiles (temperature, pressure) and a subsequent reduction of the bootstrap current. They are localised at the rational surface q= m/n. NTMs are observed in several tokamaks (e.g. ASDEX Upgrade, DIII-D, JT-60U) and experiments have been conducted to demonstrate the stabilisation of these modes by ECCD [1, 2, 3]. In ASDEX Upgrade, ECCD power is used to stabilise rotating NTMs in high confinement discharges by replacing the 'missing' bootstrap current. To be effective it is crucial to drive the ECCD current accurately at the rational surface. For the m= 3, n= 2 modes complete stabilisation at high β_N (~2.6) was successfully demonstrated in ASDEX Upgrade [4]. Following these results experiments have been performed to suppress NTMs with poloidal mode number m= 2 and toroidal mode number n= 1. Additional features, compared to the q= 3/2 surface, are the vicinity of the q= 2 surface to the vacuum vessel which may lead to mode locking, and the lower current drive efficiency caused by several effects (e.g. lower plasma temperature, trapped particles).

Suppression of m=2, n=1 NTM

In ASDEX Upgrade four gyrotrons operating at 140 GHz deliver up to 1.9 MW of RF power to the plasma. The injection of the RF beam is from the low field side, in the scenario described here, the absorption takes place at the high field side.

The deposition of the power in the plasma can be optimised by steering the launching beam in poloidal and toroidal directions. A set of Mirnov coils measures dB/dt at the plasma edge. Here, ASDEX Upgrade was operated in a lower single null high confinement mode (H-mode) with edge localised modes. The plasma current was I_p= 0.8 MA, the line averaged electron density was $<n_e>\approx 5\times10^{19}$ m^{-3}, NBI heating up to 15 MW was applied. The toroidal magnetic field was $B_t\approx$ 2 T with a variation of 10% during the discharge. If β_N is raised above the onset value of a rotating 2/1 NTM the instability grows to its saturated width (see Fig. 1, t= 1.8 – 1.9 s). Due to the proximity of the q=2 surface to the vacuum vessel in many cases the mode locks and a large reduction of β_N occurs. In the example shown in Fig. 1 β_N is decreased after mode locking to approximately half of the value before the mode onset (at full NBI power). Since the Mirnov coils monitor only dB/dt which can be due to variation of the width of a periodically rotating island or/and a change of the rotating frequency care must be taken with the interpretation of these data.

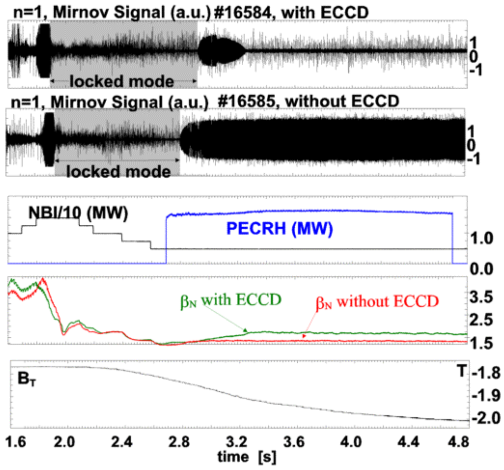

Figure 1: Comparison of two ASDEX Upgrade discharges and the effect of ECCD (#16584) on the 2/1 NTM.

To obtain a clear indication of the influence of the ECCD the NBI power is reduced, well below the onset value, before ECCD injection. Due to the low β_N value($\approx$ 1.2) the island restarts to rotate with ECCD, sometimes also without ECCD.

If ECCD is applied (#16584 in Fig. 1) the suppression of the 2/1 mode is accompanied by increasing β_N up to 30 % higher compared to the case without ECCD (#16585 in Fig. 1).

Power threshold for suppression

In previously conducted experiments on the suppression of the 3/2 NTM complete stabilisation in a steady state regime at $\beta_N\approx$ 2.6 was demonstrated. TORBEAM [5] calculations predict a driven current at the q= 3/2 surface of up to 40 kA with 1.6 MW RF power. The total driven current and the efficiency are reduced in the case of 2/1 NTM at the q= 2 surface (up to 23 kA with 1.9 MW RF power). The discharge #16999 (Fig. 2, top) shows a successful suppression of the instability by ECCD. A continuous increase of β_N can be observed until the signal of the island vanishes. The mode does not reappear if ECCD is reduced (t= 3.7 s), also not if ECCD is completely switched off (t= 4.7 s) because β_N is below the onset value.

In discharge #17000 (Fig. 2, bottom) the same parameters were chosen, but the average NBI power and thus β_N was increased from 6.25 MW to 7.5 MW. In that case, the available ECCD power is not sufficient to completely suppress the instability, the island size shrinks only to 65 %. Moreover, it is obvious that the mode increases if ECCD is reduced (t= 3.7 s) and switched off (t= 4.7 s), demonstrating the direct impact of the ECCD on the island size.

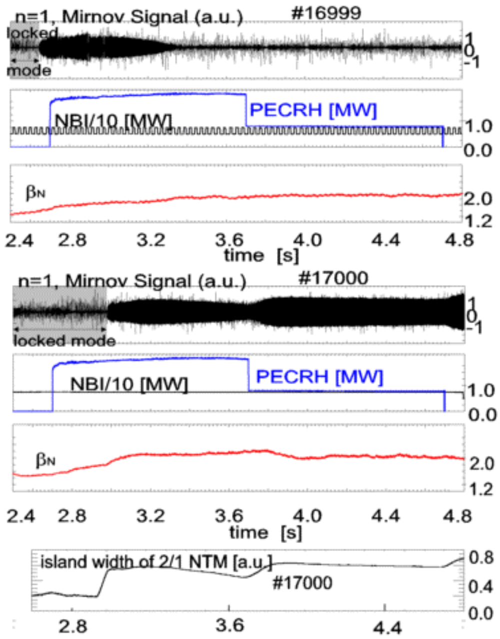

Figure 2: #16999, top: Complete suppression of 2/1 NTM. #17000, bottom: higher average NBI power, ECCD power is not sufficient for complete suppression.

Increasing β after 2/1 NTM suppression

In the case of earlier experiments at ASDEX Upgrade on 3/2 NTM stabilisation it was shown that once 3/2 mode was suppressed β could be increased above the onset value of the mode in the presence of ECCD. In Fig. 3 a discharge is given where NBI power was increased after the 2/1 mode was suppressed. Although β_N exceeds the threshold for the 2/1 mode it does not reappear during ECCD injection. At t≈ 3.8 s the 3/2 mode is triggered at β_N≈ 3.5. Due to the high β the Shafranov effect pushes the plasma towards larger R (major radius) and the deposition of the RF power, determined by the resonant magnetic field, is shifted to a larger ρ (minor radius). TORBEAM simulations (see Fig. 4) show that at t≈ 3 s

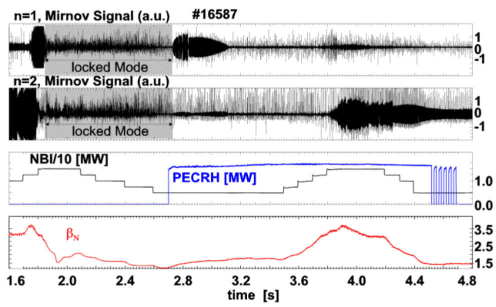

Figure 3: Time history of 2/1 (n=1) and 3/2 (n=2) NTM. The 3/2 mode is triggered at high β_N, where the deposition is shifted towards outside the q= 2 surface.

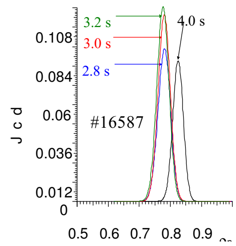

Figure 4: Current drive density vs minor radius as calculated by TORBEAM.

the ECCD power is located at the q=2 surface, the small shift at that time (t= 2.8 – 3.2 s) is caused by a feed forward variation of the magnetic field. At t≈ 4 s the ECCD power is moved to a position outside the q= 2 surface which makes the development of a 3/2 mode easier.

Enhancement of 2/1 NTM

In the discharge shown in Fig. 5 the ECCD power (here 1.6 MW) is not sufficient to suppress the 2/1 NTM. The Mirnov signal shows a decreasing behavior around t≈ 4.0 – 4.4 s. A closer analysis, taking the rotation frequency into account shows that the rotation slows down and the island is actually growing in this region (see Fig. 5, bottom). TORBEAM calculations result in a shift of the location of current drive density due to the feed forward variation of the magnetic field and a move of the deposition inside the q= 2 surface. This mismatch can also lead to a positive Δ′ (matching index, describing the jump of the radial derivative of the magnetic perturbation) and hence to an additional drive of the 2/1 island [6].

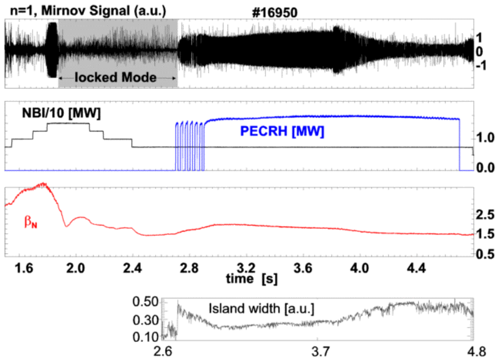

Figure 5: Growing island due to deposition of ECCD inside the q= 2 surface.

Conclusions

In this paper we showed that the suppression of the 2/1 mode is possible at ASDEX Upgrade and the required ECCD power is higher than in case of 3/2 mode stabilisation. Increasing β above the onset value is possible after 2/1 NTM suppression in the presence of ECCD, but the 3/2 NTM may possibly occur. Misalignment of the beam and the deposition of the ECCD power inside the q=2 surface showed an increase of the NTM, probably caused by an unfavorable influence on current distribution around the respective surface.

References

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